Comparison of the impact of six heat-load management strategies on thermal responses and milk production of feed-pad and pasture fed dairy cows in a subtropical environment

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Abstract Exposure to hot environments affects milk yield (MY) and milk composition of pasture and feed-pad fed dairy cows in sub-tropical regions. This study was undertaken during summer to compare MY and physiology of cows exposed to 6 heat load management treatments. Seventy-eight Holstein-Friesian cows were blocked by season of calving, parity, milk yield, BW, and milk protein (%) and milk fat (%) measured in the 2 wks prior to the start of the study. Within blocks, cows were randomly allocated to one of the following treatments: Open-sided iron roofed day pen adjacent to dairy (CID) + sprinklers (SP); CID only; Non-shaded pen adjacent to dairy + SP (NSD+SP); Open–sided shade cloth roofed day pen adjacent to dairy (SCD); NSD + sprinkler (sprinkler on for 45 min at 1100 h if mean respiration rate > 80 breaths per minute (NSD+WSP)**)**; Open-sided shade cloth roofed structure over feed bunk in paddock + 1 km walk to and from the dairy (SCP+WLK). Sprinklers for CID+SP and NSD+SP cycled 2 min on, 12 min off when ambient temperature > 26ºC. The highest milk yields were in the CID+SP and CID treatments (23.9 $L \cdot cow^{-1} \cdot day^{-1}$), intermediate for NSD+SP, SCD and SCP+WLK (22.4 $L \cdot cow^{-1} \cdot day^{-1}$), and lowest for NSD+WSP (21.3 $L \cdot cow^{-1} \cdot day^{-1}$) ($P < 0.05$). The highest ($P < 0.05$) feed intakes occurred in the CID+SP and CID treatments while intake was lowest ($P < 0.05$) for NSD+WSP and SCP+WLK. Weather data were collected on site at 10 min intervals, and from these THI was calculated. Nonlinear regression modelling of MY × THI and heat load management treatment demonstrated that cows in CID+SP showed no decline in MY out to a THI break point value of 83.2, whereas the pooled MY of the other treatments declined when THI > 80.7. A combination of iron roof shade plus water sprinkling throughout the day provided the most effective control of heat load.

Key words Heat-load · Cooling strategies · Sub-tropical · Dairy production

Introduction

High ambient temperature and humidity in sub-tropical and tropical regions have a negative impact on milk production, milk composition and reproductive performance of dairy cows, with this impact being greater in higher producing herds (Davison et al. 1988; Mayer et al. 1999; Morton et al. 2007). Similar effects have been demonstrated in the warmer areas of the USA (Johnson et al. 1962; Berry et al. 1964; Ingraham et al. 1974; West 2003) and southern Africa (du Preez et al. 1990). Annual losses to the US dairy industry from increased heat load have been estimated to be approximately US$897 million (St-Pierre et al. 2003). In Australia it has been estimated that a moderate production herd (25 L/d) may experience losses of 59 to 461 L·cow^{-1}·year^{-1} depending on the management strategies employed (Mayer et al. 1999).

In dairies heat load is usually managed by the use of shade, fans, sprinklers or various combinations of these (West 2003; Chen et al. 2015). It is well known that the application of water (in association with adequate air flow) will reduce body temperature, respiration rates and will minimise reductions in feed intake and milk yield during periods of hot weather (Flamenbaum et al. 1986; Means et al. 1992; Chen et al. 2013; Chen et al. 2015). In many instances shade is the most economical option for reducing heat load. Shade will reduce the impact of solar load (Bond et al. 1967; Curtis 1983), but has little impact on air temperature. Therefore other strategies such as the use of fans and water application are required. Water is a limited resource in many regions worldwide and therefore there is a need to investigate options which will limit water application whilst maintaining production and welfare of dairy cows. The amount of water required to effectively cool cows is affected by the severity of heat load to which cows are exposed, cow productivity, ventilation and airflow over the cows. There is large variation in published water usage for cooling cows. Means et al. (1992) reported that there were no differences in performance of cows wetted with either: 215 L·cow^{-1}·day^{-1}, 321 L/cow/d or 456 L·cow^{-1}·day^{-1}. Using a 5 × 570 L daily water application on 24 cows, Flamenbaum et al. (1986) reported a total water use of 2850 L or 118 L·cow^{-1}·day^{-1}. More recently Chen et al. (2015) reported that water application of 1.3 L/min was sufficient to cool cows in a hot dry environment when an intermittent spray schedule was used.

Much of the published work regarding cooling strategies for dairy cows has focused on cows housed in feedlots or barns. Relatively few studies (e.g. Davison et al. 1988; Valtorta and Gallardo 2004; Tucker et al. 2008; Schütz et al. 2014) have investigated cooling options for cows that are largely pasture based. Determining the optimal cooling system is a function of infrastructure costs, running cost, available resources (electricity and water) and location. The primary objective of this experiment was to determine the effects on milk production and milk quality when different types of shade structures, sprinklers and combinations of shade and sprinklers were applied to grazing lactating Holstein-Friesian cows during summer in a sub-tropical environment. The impact of these different heat-load management strategies on cow feed intake and thermal responses was also investigated.

Materials and methods

Treatments and animal management

The experiment was conducted over a 92 day period during Australian summer (13 December to 16 March) at the Mutdapilly Research Station (latitude 27^{O} 46' S, longitude 152^{O} 40' E, elevation 40 m) located southwest of Brisbane, Australia. The Animal Ethics Committee of the Department of Agriculture, Fisheries and Forestry (Queensland) approved this experiment. All treatments had some form of heat-load alleviation to minimise negative animal welfare impacts. The climate at Mutdapilly is characterized as sub-tropical with hot wet summers and cool dry winters. The long term climate averages (30 + years) for the period December to March are: mean (of the four month period) maximum and minimum ambient temperature of 31.5 ± 1.2 ^{o}C and 17.8 ± 1.2 ^{o}C respectively; mean relative humidity at 0900 h was 79.1 ± 7.7%; mean monthly rainfall was 95.9 ± 55.5 mm.

Seventy-eight lactating Holstein-Friesian cows were used in the study. Eighteen of these calved in the autumn (March and April) and 60 calved in spring (September and October). The cows were blocked by season of calving, parity, milk yield, live weight, and by the percentage of milk protein and milk fat in the 2 weeks prior to the start of the experiment. Within blocks the cows (n=13/treatment) randomly allocated to one of the following heat-load management treatment groups: 1. Open-sided corrugated iron roofed day pen adjacent to dairy + sprinklers (CID+SP); 2. CID only; 3. Non-shaded day pen adjacent to dairy + SP (NSD+SP); 4. Open–sided shade cloth (Rheem Australia Pty Ltd, 65% solar block) roofed day pen adjacent to dairy (SCD); 5. NSD + sprinkler (NSD+WSP**);** a 45 min sprinkler treatment at 1100 h at the dairy holding pen if mean respiration rate exceeded 80 breaths per minute; 6. Open-sided shade cloth (Rheem Australia Pty Ltd, 65% solar block) roofed structure over a feed bunk (feed bunk was shaded) in an improved pasture paddock (see below) + 1 km walk to and from the dairy (SCP+WLK). Cows in treatment groups 1, 2, 3, 4 and 6 had continuous access to the applied cooling throughout the day. The shade structure for treatment 6 was located in a day paddock 1 km from the dairy with a pen layout the same as the pens at the dairy. Each treatment pen (9.1 m wide × 13.1 m deep) provided a stocking rate of 9.17 m^2/cow. Water was provided *ad libitum* via an unshaded round concrete water trough located in the northern end of each treatment pen. Each water trough was metered and water usage was recorded daily at 1530 h. Shade (9.1 m × 8.3 m) was orientated east-west and provided a midday shade foot print of 5.81 m^2/cow. The corrugated iron shade was provided by a gable roof structure with an open ridge vent. The structure was 2.40 m in height at low side and 3.25 m in height at the apex. The ridge vent opening was 350 mm.

In the shaded pens the shade was located across the southern end of the pen (over a feed bunk). In the sprinkler treatments the sprinklers were also located along the southern end of the pens. A concrete apron (1.8 m) extended past the shade area and the remainder of the pen surface was dirt. Water only sprayed on the concreted area. Sprinklers for treatments CID+SP, NSD+SP cycled 2 min on, 12 min off when ambient temperature exceeded 26 ºC (RCC-2; Rotem, Petach Tikva, Israel). The sprinklers for all sprinkler treatments (90º spray; 151 kPa pressure; 150 µm) were spaced 1.7 m apart (5 sprinklers/pen) and were 3.2 m above the pen surface. Each sprinkler delivered approximately 2 L/min. For the NSD+WSP treatment the sprinklers are as mentioned above but covered the entire dairy holding yard. The sprinkler output and droplet size at the dairy and within the treatment pens was sufficient to wet cattle to the skin. No forced air movement was used in any of the treatments.

At 1530 h each day cows were walked to a shade cloth covered holding yard at the dairy for afternoon milking and at 1630 h the cows were taken as a single group to a night grazing paddock. At night the cows were offered approximately 12 kg DM/cow of a fresh strip of alfalfa (*Medicago sativa*) and Rhodes grass (*Chloris gayana)* pasture which contained approximately 80% alfalfa and 20% Rhodes grass on a DM basis. The cows were walked in from the pasture for milking at 0500 h each morning. Following milking the cows within each treatment (except SCP+WLK) were taken to their respective treatment pens, located approximately 100 m from the dairy. After milking the SCP+WLK cows walked to a day pasture located 1 km from the dairy.

In each treatment pen cows had, while they were in their respective day time treatment locations, *ad libitum* access to a mixed ration (MR). The MR was formulated (RUMNUT v 3.0 ration formulation program) to provide 16% crude protein (CP), 10.1 MJ/kg ME and 35% neutral detergent fibre (NDF) on a dry matter basis. The MR (dry matter (DM) basis) was: corn silage, 22.3% (10.8 MJ/kg ME, 8.7% CP and 38.7% NDF); alfalfa hay, 35% (9.4 MJ/kg ME, 18.9% CP and 41.2% NDF %); sodium hydroxide treated sorghum, 13.5% (12.8 MJ/kg ME, 12.5% CP); cotton seed meal, 9% (12.2 MJ/kg ME, 45% CP); meat and bone meal, 9% (7.6 MJ/kg ME, 58.4% CP) (*the study was undertaken prior to the Australian banning of meat products in ruminant* *diets*); cane molasses, 9.4% (10.8 MJ/kg ME, 9.7% CP); magnesium oxide, 0.25%; urea, 1.5% and a vitamin and mineral premix, 0.005%.

The quantity of MR offered and refused for each treatment group was recorded daily and samples of offered and refused feed were taken twice weekly to determine DM content. Also a weekly sample of the MR offered was obtained for chemical analyses. Pasture DM yields were monitored each week by cutting 10 × 0.25 m^2 quadrats and drying a sub-sample in a forced draught oven at 80 °C for 24 h with a sample kept for chemical analyses. Over the duration of the experiment the nutrient content of the pasture on a DM basis averaged 10.6 MJ ME/kg, 23.5% CP and 35.8% NDF. The MR averaged 9.8 MJ ME/kg, 16.6% CP, and 36% NDF.

Climatic measurements

The following weather parameters were recorded at 30 min intervals from an automated weather station (Esidata MK-3; Environdata Australia P/L, Warwick, Qld., Australia): ambient temperature, (°C; T_A), relative humidity, (%; RH) and wind speed, (WS, m/s). Rainfall data was collected daily at 0900 h. The weather station was located in a laneway approximately 10 m from the treatment pens. The temperature humidity index (THI) was used to determine cow heat load and was calculated using the following equation (adapted from Thom, 1959): THI = $\{(0.8 \times T_A) + [RH \times (T_A - 14.3)] + 46.4\}$, where RH is in decimal form.

Animal measurements

Milk yield for each cow was recorded at the morning and afternoon milking. Milk samples from each cow were analysed for fat (%), lactose (%), protein (%) and somatic cell count (SCC) per mL of milk (Foss Milkoscan 605; Foss Electric, Hillerod, Denmark) once a week using a combined sample from the morning and afternoon milking.

Cow BW were obtained following the morning milking on day 1 (Wednesday at 0800 h) and then at 7 day intervals throughout the experiment. Individual respiration rates (RR) and rectal temperatures (RT) of the cows were measured Monday to Thursday each week starting at 1330 h. The cows were walked within treatment groups (1 to 5) approximately 12 m to shaded individual feeding stalls. For treatment 6 (SCP+WLK) RR and RT were measured in the individual stalls after the 1 km walk from the paddock. Respiration rate was calculated by counting the numbers of breaths taken during 20 s and multiplied by 3. Rectal temperature was recorded using a digital thermometer placed 8 to 10 cm into the rectum. The measurement of RR and RT took approximately 1 min per animal. Cows were moved back to their respective treatment pens (apart from

SCP+WLK) after data was obtained. The SCP+WLK was the last group measured. The cows from this treatment and treatments 1 to 5 were then all moved to the dairy for the afternoon milking.

Cows were inseminated with commercially available frozen-thawed semen from proven Holstein sires at the milking closest to 12 h after onset of oestrus. Pregnancy was diagnosed by manual (rectal palpation) and ultrasound (real-time, B-mode machine equipped with a 5 MHz, linear-array, intrarectal transducer; SSD, 500 V, Aloka Co., Tokyo, Japan), 5 to 8 weeks after insemination.

Statistical analyses

All analyses were conducted using GenStat (2008). The statistical design was a randomised block (6 treatments × 13 blocks). The variables were recorded on repeated occasions (daily or weekly) throughout the experiment. As these observations are not independent, split-plot ANOVAs were used, with the split level being for the relevant time factor. Here the treatment comparisons remain statistically valid, as the blocks of animals contribute the appropriate error term. A balanced allocation of animals to treatments was achieved, as none of the pre-trial measures were different between treatments ($P > 0.05$). Where appropriate and significant, these pre-trial measures were used as covariates in the analyses of trial data. Differences between means were determined by protected least significant difference (LSD) testing. Categorical data were tested via generalised linear models (McCullagh and Nelder 1989).

Relationships between the animal response and meteorological variables were investigated via linear and nonlinear regression analyses, with the interaction between the independent variates and treatments being tested. THI was included, as animal responses have been shown to correlate better with this variable than with the base meteorological measures (Mayer et al. 1999). Similarly, the black-globe THI and wind speed, measured separately within each treatment, was included in these regression analyses. Due to animal differences (which had been accounted for by the blocks term in the ANOVA's), stage of lactation was fitted first in the multiple regressions for milk yield.

Results

Observed maximum and minimum dry-bulb temperatures and mean THI's during the experimental period which includes a 15 day heat stress period (defined as THI > 81 on 3 or more consecutive days) are summarised in Table 1. Over the 92 days of the experiment, mean daily milk, and component yields were higher ($P < 0.05$) for the two treatments that used corrugated iron shade with CID+SP the best compared with the other treatments, while SCD and SCP+WLK were similar to NSD+SP and NSD+WSP had the lowest ($P < 0.05$) milk yield (Table 2). Fat, protein and lactose percentages were not affected ($P > 0.05$) by treatment. Somatic cell counts were not significantly different ($P > 0.05$) between treatments, and ranged from (163,000 cells/mL to 342 cells/mL. Although not statistically significant the SCC of the CID+SP (163,000 cells/mL) was 52% lower than the worst performing treatment (SCD; 342,000 cells/mL) and 35% better than the second best performing treatment (SCP+WLK: 249,000 cells/mL). The highest ($P < 0.05$) MR intakes occurred in the CID+SP and CID treatments while intake was lowest ($P < 0.05$) for NSD+WSP and SCP+WLK. Over the duration of the study the RT and RR were lowest ($P < 0.05$) in the CID+SP treatment (38.9 ± 0.09 °C and 61.3 ± 2.8 breaths per minute: bpm) and greatest ($P < 0.05$) for the NSD+WSP treatment (40.1 ± 0.09 °C and 90.8 ± 2.8 bpm) (Figure 1 and Figure 2). During the 15 day heat event RT and RR were lowest in the CID+SP treatment (39.0 ± 0.11 °C and 67.0 ± 3.8 bpm) and highest in the NSD+WSP treatment (41.0 ±11 °C and 119.0 ± 3.8 bpm). During the 15 day heat event RT and RR increased ($P<0.05$) for all treatments except CID+SP. At the commencement of the study the mean BW (mean ± SE) of the cows was 544.0 ± 15.6 kg. There were no differences among treatments ($P < 0.05$) for weight change over the 92 d experimental period (Table 2). However the cows in the CID+SP group gained on average 21.6 kg/cow, and the SCP+WLK cows had virtually no change in BW. However, all groups lost weight during the 15 day heat event (Table 3), with the largest loss ($P<0.05$) occurring in the NSD+SP group (9.2 kg/cow).

Pregnancy rates were higher (80%: $P < 0.05$) for the CID+SP group at the end of the 92 d experimental period compared to the other treatments. The treatments with no shade (NSD+SP and NSD+WSP) had the lowest pregnancy rates (20%), whereas the pregnancy rates of shade only treatments (CID, SCD, SCP+WLK) were approximately 47%.

The observed animal responses were all correlated with the meteorological variables recorded. In particular, respiration rates and rectal temperatures were correlated with maximum ambient temperatures (r = 0.74 and 0.76 respectively), and daily milk yield was negatively correlated with THI (r = -0.42). Modeling of the relationship between milk yield and THI demonstrated that the bent-stick relationship (with zero slope up until the fitted break-point) provided the best fit. Lagged multiple non-linear regressions with THI were subsequently investigated, with significant coefficients found for the direct (same-day) effect plus lags out to day 3. The final model for milk yield, with stage of lactation and heat-load management treatment interaction with THI for lags 0 to 3 day inclusive, had an overall R^2 of 80.5%.

The major contrast in these regressions was between what was considered the ‘best practice’ treatment (CID+SP) and all the other treatments. For milk yield, CID+SP showed no decline out to a THI fitted break point value of 83.2, whereas the pooled milk yield of the other treatments declined when THI was greater than 80.7. The estimated rates of decline were similar, being 0.89 $L\cdot cow^{-1}\cdot day^{-1}$ per THI unit greater than the break point for CID+SP, and 0.92 $L\cdot cow^{-1}\cdot day^{-1}$ for the other treatments. Similar results were obtained for fat percentage with a flat response of 3.74% fat for THI values up to the bent stick break point of 83.8 for the CID + SP treatment and 82.4 for the others. Above these break points the rate of decline was the same; 0.04% fat for each THI unit above the respective break points. There were no relationships ($P > 0.05$) between protein and lactose percentage and THI.

During the 15 day period of severe heat stress the mean THI was 84.7 (Table 1). Cows in the CID+SP group had a significantly lower ($P < 0.05$) mean rectal temperature and higher daily milk production (39 °C and 22.9 $L\cdot cow^{-1}\cdot day^{-1}$, respectively) than cows in the other heat load management treatment groups (39.9 to 41.0 °C and 17.6 to 20.8 $L\cdot cow^{-1}\cdot day^{-1}$, respectively, Table 3).

Discussion

The current experiment was conducted to evaluate the effects on milk production and cow physiology where cows were managed under a range of heat-load mitigation strategies which could be readily implemented on dairy farms in a sub-tropical environment. Although not significantly different the greater weight gain in the CID+SP cows could have biological significance. Changes in BW in lactating dairy cows provides an indication of a cow’s energy status, and it is well known that body weight and body condition score (not assessed here) have a significant influence on fertility. The weight gain and the higher pregnancy rate in the CID+SP group demonstrate the effectiveness of this strategy. Furthermore the overall milk yield of the CID+SP group was 2.9 $L\cdot cow^{-1}\cdot day^{-1}$ greater than the worst treatment (NSD+WSP); over the 92 day experimental period this resulted in a greater overall milk yield of 267 L/cow in the CID+SP system. Not surprisingly, the treatment effects were most pronounced during the periods when THI ≥ 81, with CID+SP cows producing on average 5.3 $L\cdot cow^{-1}\cdot day^{-1}$ more milk compared with the NSD+WSP cows. This is the first report comparing different cooling strategies to pasture fed cattle in a subtropical environment. The trends reported here need to be confirmed in systematic field studies.

Rodriquez et al. (1985) reported that milk yield in Holstein cows decreased rapidly after daily maximum temperatures exceeded 29°C, but did not quantify the magnitude of the effect. In a 33 day grazing study Valtorta and Gallardo (2004) reported no differences ($P > 0.05$) in overall milk yield between shade only (22.14 L/d) and cows cooled with sprinklers + fans (23.18 L/d). However they did report that on days when THI ≥ 72 MY of the cooled cows was 1.1 L·cow^{-1}·day^{-1} greater ($P > 0.05$) than then non-cooled cows. Milk production in the current study were similar to that reported by Valtorta and Gallardo (2004). Production levels are likely to influence the negative effects of heat load on MY. Lees and Gaughan (2011) reported that although reductions in milk yield from grazing cows in a sub-tropical was a function of ambient conditions they were also a function of genetic capacity, with high production cows (MY = 35 L/d) being affected to a greater extent (-2.24 L/d) than low production cows (MY = 20 L/d: -0.66 L/d), when exposed to high heat loads.

In the current study milk component percentages were not significantly affected by treatments, both overall and during the period of severe heat stress. Over the duration of the study the CID+SP cows had higher ($P < 0.05$) fat and protein yield compared with the other treatment groups, which is largely a reflection of the higher MY within this group.

A significant linear decline in the protein and fat percentage in milk as ambient temperature increased from 8 to 37 °C was reported by Rodriquez et al. (1985). This is in agreement with Bernabucci et al. (2002) who found that there was a reduction in milk protein during the summer months. In contrast Ominski et al. (2002) found no difference in protein and fat percentage in milk when cows were exposed to either thermoneutral conditions or short-term heat stress. The results from the current experiment showed no treatment differences for protein and fat percent; however the trends were consistent with Rodriquez et al. (1985) in regards to percentage fat. In the current experiment overall milk fat was 7.2% greater ($P > 0.05$) in the CID+SP cows compared with the CID cows. However during the high heat load period the difference was 8.4%. Investigating cooling options in a free stall barn (fan, or fan + sprinklers) or paddock with limited cooling Lin et al. (1998) reported seasonal effects on milk fat and milk protein. Milk fat percentage was greater (11.2%) in the cooled cows with shade, fans and sprinklers compared with the controls (paddock + limited fan access). Improvements in milk protein (9%) and fat (4%) were reported by Valtorta and Gallardo (2004) when grazing cows were cooled before morning and afternoon milking. It is evident that summer conditions will result in a decrease in milk protein. The protein losses associated with summer can be somewhat offset by cooling.

The difference between the mean rectal temperatures of the best and worst treatments in the present study of 1.2°C was notably greater than the 0.2 °C reported by Fuquay (1981) and the 0.5 °C difference reported by Chen et al. (2015) for cooled (water application) and non-cooled cows (no water application). The highest overall mean rectal temperature was 40.1 °C for the NSD+WSP treatment, and the lowest mean rectal temperature was 38.9 ºC in the CID+SP treatment. These values are close to those reported by Wolfenson et al. (1995) for non-cooled and cooled cows of 40.3 and 38.8 ºC, and by Flamenbaum et al. (1995) at 39.7 and 38.6 ºC, respectively for non-cooled and cooled cows. The range reported by Chen et al. (2015) was 39.72 ºC for non-cooled cows to 39.05 ºC for cows cooled with water applied at 4.5 L/min. In the same study cows cooled with every 0.4 L/min had a rectal temperature drop of 0.4 ºC relative to non-cooled cows.

In the current study milk production was reduced on each day that THI was above the break point plus the following 3 days (a lag period). Similarly a 2 to 4 day lag period was reported by Lees and Gaughan (2011) for Holstein-Friesian grazing cows during periods of heat stress in a sub-tropical environment. Overall and somewhat surprisingly wind speed contributed very little to the regressions, either by itself or in addition to the other variables in the multiple regression analysis.

The greater THI threshold observed in the current study may due to acclimation, but may also be a factor of the moderate milk yields of the cows. In the current study the THI bent stick break point values showed milk yield and fat % depression of 0.9 L/cow.d and 0.04% for each increase in THI > 81 which is considerably higher that the THI > 60 threshold reported by Brügemann et al. (2012) for cows in Germany. The differences may be an indication that the Queensland cows are somewhat adapted to the hotter conditions to which they are typically exposed. The current study also demonstrated a higher THI break point for the coolest cows (CID+SP) of 2.5 and 1.4 THI units for milk yield and percentage fat, respectively, above the other treatments. The current study also demonstrated that solid shade (CID) is superior to partial shade provided by the shade cloth, which is in agreement with Gaughan et al. (1998).

The fact that increasing heat load will reduce DMI of dairy cows is well documented (West, 2003), and the positive effects of cooling on the DMI of TMR fed cows is also well documented. However the effects on pasture DMI of cooled grazing cows has not been adequately studied. Measurement of PMR or TMR intake by dairy cows provides an insight into changes in DMI, but measurement of pasture intakes are not that easy to define. Relative to the whole of study MR intakes decreased during the heats stress period for all treatments. During the heat stress period the optimally cooled cows (CID+SP) had a MR reduction of 0.2 kg/d relative to whole of study, compared with 3.5 kg/d reduction for the SCP+WLK cows. On average, during the heat stress period all cows lost weight. It would be expected that the largest weight losses would occur within treatments with the largest reductions in MR intake (SCP+WLK). However this was not the case, and it may be that the reductions in MR were offset by increased grazing within this treatment, although this was not quantified. The treatment with greatest weight loss (NSD+SP; 4.6 kg/wk) had a 1.4 kg/d reduction in MR which was the lower of all treatments except CID+SP. Clearly other factors are playing a role which highlights the need for more work in this area.

The SCC differences although not significantly different between treatments tended to show that the cows in the treatments which had the greatest impact on reducing heat load had the lowest SCC.

Managing cows during the day in an appropriately designed solid shaded pen close to dairy minimises the impact of walking in hot environmental conditions, and when combined with automated sprinkling will provide the most effective control of heat-load in sub-tropical-tropical dairying areas.

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References

Berry IL, Shanklin MD, Johnson HD (1964) Dairy shed design based on milk production decline as affected by temperature and humidity. Trans ASEA 7:329 – 331

Bond TE, Kelly CF, Morrison SR, Pereira N (1967) Solar, atmosphere, and terrestrial radiation received by shaded and unshaded animals. Trans ASAS 10:622 – 629

Bernabucci U, Lacetera N, Ronchi B, Nardone A (2002) Effects of the hot season on milk protein fractions in Holstein cows. Anim Res 51:25 – 33

Brügemann K, Gernand E, von Borstel UK, König S (2012) Defining and evaluating heat stress thresholds in different dairy cow production systems. Archiv Tierzucht 55:12 – 24

Chen JM, Schütz KE, Tucker CB (2013) dairy cows use and prefer feedbunks fitted with sprinklers. J Dairy Sci 96:5035 – 5045

Chen JM, Schütz KE, Tucker CB (2015) Cooling cows efficiently with sprinklers: Physiological responses to water spray. J Dairy Sci doi.org/10.3168/jds.2015-9434

Curtis SE (1983) Environmental management in agriculture. Iowa State University Press, Ames, IA

Davison TM, Silver BA, Lisle AT, Orr WN (1988) The influence of shade on milk production of Holstein-Friesian cows in a tropical upland environment. Aust J Exp Agr 28:149 – 154

du Preez JH, Giesecke WH, Hattingh PJ (1990) Heat stress in dairy cattle and other livestock under southern African conditions. I. Temperature-humidity index mean values during the four main seasons. Onderstepoort J Vet Res 57:77 – 87

Dunshea FR, Leury BJ, Fahri F, DiGiacomo K, Hung A, Chauhan S, Clarke IJ, Collier R. Little S, Baumgard L, Gaughan JB (2013) Amelioration of thermal stress impacts in dairy cows. Anim Prod Sci 53:965 – 975

Flamenbaum I, Wolfenson D, Mamen M, Berman A (1986) Cooling dairy cows by a combination of sprinkling and forced ventilation and its implementation in the shelter system. J Dairy Sci 69:3140 – 3147

Flamenbaum I, Wolfenson D, Kunz PL, Mamen M, Berman A (1995) Interactions between body condition at calving and cooling of dairy cows during lactation in the summer. J Dairy Sci 78:2221 – 2229

Fuquay JW (1981) Heat stress as it affects animal production. J Anim Sc 52:164 – 174

Gaughan JB, Goodwin PJ, Schoorl TA, Young BA, Imbeah M, Mader TL, Hall A (1998) Shade preferences of lactating Holstein-Friesian cows. Aust J Exp Agric 38:17 – 21

Gaughan JB, Lees JC (2010) Categorising heat load on dairy cows. Proc Aust Soc Anim Prod 28:105

GenStat (2008) GenStat for Windows, Release 11.1, Eleventh Edition. VSN International Ltd., Oxford

Ingraham RH, Gillette DD, Wagner WD (1974) Relationship of temperature and humidity to conception rate of Holstein cows in subtropical climate. J Dairy Sci 57:476 – 481

Johnson HD, Ragsdale AC, Berry IL, Shanklin ND (1962) Effect of various temperature-humidity combinations on milk production of Holstein cattle. University of Missouri Research Bulletin ZZ 791:1 – 39

Lambertz C, Sanker C, Gauly M (2014) Climatic effects on milk production traits and somatic cell score in lactating Holstein-Friesian cows in different housing systems. J dairy Sci 97:319 – 329

Lees JC, Gaughan JB (2011) Effect of yearly climate on milk yield in a sub-tropical environment. J Anim Sci 89 (E-Suppl. 1): 412

Lin JC, Moss BR, Koon JL, Flood CA, Smith III RC, Cummins KA, Coleman DA (1998) Comparison of various fan, sprinkler, and mister systems in reducing heat stress in dairy cows. Appl Eng Agric 14:177 – 182

Mayer DG, Davison TM, McGowan MR, Young BA, Matschoss AL, Hall AB, Goodwin PJ, Jonsson NN, Gaughan JB (1999) Extent and economic effect of heat loads on dairy production in Australia. Aust Vet J 77:804 – 808

McCullagh P, Nelder JA (1989) Generalized Linear Models (2nd ed). Chapman and Hall, London, UK

Means SL, Bucklin RA, Nordstedt RA, Beede DK, Bray DR, Wilcox CJ, Sanchez WK (1992) Water application rates for a sprinkler and fan cooling system in hot humid climates. Trans ASAE 8:375 – 379

Morton JM, Tranter WP, Mayer DG, Jonsson NN (2007) Effcts of environmental heat on conception rates in lactating dairy cows: critical periods of exposure. J Dairy Sci 90:2271 – 2278

Ominski KH, Kennedy AD, Wittenberg KM (2002) Physiological and production responses to feeding schedule in lactating dairy cows exposed to short-term, moderate heat stress. J Dairy Sci 85:730 – 737

Rodriguez LA, Mekonnen G, Wilcox CJ, Martin FG, Krienke WA (1985) Effects of relative humidity, maximum and minimum temperature, pregnancy and stage of lactation on milk composition and yield. J Dairy Sci 68:973 – 978

RUMNUT v 3.0 Dairy ration formulation using international standards by AT Chamberlain Shedfield Southampton UK. www.rumnut.com [Verified 7 July 2011]

St-Pierre NR, Cobanov B, Schnitkey G (2003) Economic loses from heat stress by US livestock industries. J Dairy Sci 86 (E Suppl):E52 - E57

Schütz KE, Cox NR, Tucker CB (2014) A field study of the behavioral and physiological effects of varying amounts of shade for lactating cows at pasture. J Dairy Sci 97:3599 – 3605

Thom EC (1959) The discomfort index. Weatherwise. 12:57 – 59

Tucker CB, Rogers AR, Schütz KE (2008) Effect of solar radiation on dairy cattle behaviour, use of shade and body temperature in a pasture-based system. Appl Anim Behav Sci 109:141 – 154

Valtorta SE, Gallardo MR (2004) Evaporative cooling for Holstein dairy cows under grazing conditions. Int J Biometeorol 48:213 – 217

West JW (2003) Effects of heat-stress on production in dairy cattle. J Dairy Sci 86:2131 – 2144

Wolfenson D, Thatcher WW, Badinga L, Savio JD, Meidan R, Lew BJ, Braw-Tal R, Berman A (1995) Effect of heat stress on follicular development during the oestrous cycle in lactating dairy cattle. Biol Reprod 52:1106 – 1113

Table 1 Mean maximum dry-bulb temperature (TA_{Max}; ºC), TA_{Max} range, mean minimum dry-bulb temperature (TA_{Min}; ºC), TA_{Min} range, mean relative humidity (RH, %), mean temperature humidity index (THI) and THI range over the duration of the experiment (92 day; whole of experiment) and for a 15 day heat stress period.[1]

	TA_{Max}, ºC	TA_{Min}, ºC	RH, %	THI
Whole of experiment	30.6 ± 8.2 (22.9 to 38.8)	17.9 ± 6.5 (11.3 to 24.1)	64.8 ± 24.1 (36.0 to 100.0)	78.8 ± 7.8 (72.1 to 89.2)
Heat stress period	35.5 (32.6 to 38.8)	21.4 (19.7 to 24.1)	63.8 (42.0 to 100.0)	84.7 (81.7 to 89.2)

[1]Heat stress period: defined as THI > 81 on 3 or more consecutive days.

Table 2 Effect of six cooling strategies[A] on milk yield, milk composition, somatic cell count (SCC), mixed ration (MR) intake, water intake (WI), BW change, respiration rate (RR; breaths per min), rectal temperature (RT), percent eating (EAT), and percent ruminating (RUM) of lactating dairy cows over a 92 day period.

	CID	CID+SP	NSD+SP	SCD	NSD+WSP	SCP+WLK	SE
Milk, L/d	23.5^{ab}	24.2^{a}	22.5^{bc}	22.5^{bc}	21.3^{c}	22.3^{bc}	0.52
Fat, %	3.63	3.91	3.73	3.58	3.85	3.77	0.08
Fat, kg/d	0.85^{b}	0.94^{a}	0.84^{b}	0.80^{b}	0.83^{b}	0.83^{b}	0.02
Protein, %	2.99	3.01	3.00	2.98	3.00	3.00	0.03
Protein, kg/d	0.70^{ab}	0.72^{a}	0.67^{bc}	0.66^{bc}	0.65^{c}	0.67^{bc}	0.02
Lactose, %	4.87	4.89	4.90	4.90	4.88	4.84	0.03
Lactose, kg/d	1.14^{a}	1.17^{a}	1.10^{ab}	1.11^{ab}	1.05^{b}	1.08^{b}	0.03
SCC, 000/mL	294	163	290	342	266	249	76.7
MR intake, kg/d	14.6^{a}	14.9^{a}	13.7^{b}	13.6^{bc}	13.4^{cd}	12.7^{d}	0.1
BW change, kg/wk	0.81	1.66	0.75	1.41	0.40	-0.07	0.62
WI, L/d	72.0^{a}	68.5^{b}	77.6^{c}	62.5^{d}	66.5^{bf}	65.8^{f}	0.9
RR, bpm	70.3^{b}	61.3^{c}	73.1^{b}	71.0^{b}	90.8^{a}	85.1^{a}	2.8
RT, °C	39.2^{c}	38.9^{d}	39.4^{bc}	39.5^{b}	40.1^{a}	40.0^{a}	0.09
EAT, %	33.1^{a}	30.1^{b}	23.7^{c}	35.1^{a}	22.7^{c}	22.3^{c}	1.8
RUM,%	10.4^{a}	8.6^{a}	18.8^{b}	9.8^{a}	12.3^{ca}	18.2^{bc}	1.54

[A]Corrugated iron shade only (CID); Corrugated iron shade and sprinklers (CID+SP); No shade with sprinklers (NSD+SP); Shade cloth (SCD) (Rheem Australia Pty Ltd, 65% solar block); No shade but managed (NSD+WSP); cows were assessed at 1100 h and if mean respiration rate exceeded 80 breaths per minute the cows were walked 100 m to the dairy and sprinkled continuously for 45 min and then returned to their day treatment pen; Shade cloth (Rheem Australia Pty Ltd, 65% solar block) and a 2 km return walk to the milking shed between morning and afternoon milking (SCP+WLK). Within rows, means with common super-scripts do not differ (*P*>0.05).

Table 3 Effect of six cooling strategies[A] on milk yield (kg), milk composition (% and kg), somatic cell count (SCC: 1000/mL), mixed ration (MR) intake (kg/d), water intake (WI, L/d), BW change (kg), respiration rate (RR; breaths per min) and rectal temperature (RT, oC) of lactating dairy cows over a 15 day period of severe heat stress (defined as THI > 81 on 3 or more consecutive days).

	CID	CID+SP	NSD+SP	SCD	NSD+WSP	SCP+WLK	SE
Milk, L/d	20.8^{b}	22.9^{a}	20.0^{b}	19.6^{b}	17.6^{c}	19.4^{bc}	0.71
Fat, %	3.49	3.81	3.48	3.43	3.66	3.78	0.13
Fat, kg/d	0.72^{b}	0.86^{a}	0.69^{b}	0.66^{b}	0.65^{b}	0.72^{b}	0.03
Protein, %	2.85	2.94	2.88	2.86	2.83	2.85	0.04
Protein, kg/d	0.59^{b}	0.66^{a}	0.57^{b}	0.55^{bc}	0.51^{c}	0.55^{bc}	0.02
Lactose, %	4.78	4.87	4.88	4.87	4.81	4.81	0.04
Lactose, kg/d	1.00^{b}	1.11^{a}	0.97^{b}	0.96^{b}	0.85^{c}	0.93^{bc}	0.04
SCC, 000/mL	255	153	339	464	382	201	143
MR intake, kg/d	12.8^{b}	14.7^{a}	12.3^{b}	11.7^{c}	11.2^{c}	9.2^{d}	0.2
WI, L/d	74.1^{a}	66.8^{b}	79.8^{a}	56.0^{c}	59.1^{c}	53.7^{c}	2.2
BW change, kg/wk	-1.3^{a}	-0.6^{a}	-4.6^{b}	-1.3^{a}	-2.2^{ab}	-0.4^{a}	0.89
RR, bpm	95^{bc}	67^{d}	92^{c}	97^{bc}	119^{a}	103^{b}	3.8
RT, ºC	39.9^{c}	39.0^{d}	40.1^{c}	40.5^{b}	41.0^{a}	40.7^{ab}	0.11

[A]Corrugated iron shade only (CID); Corrugated iron shade and sprinklers (CID+SP); No shade with sprinklers (NSD+SP); Shade cloth (SCD) (Rheem Australia Pty Ltd, 65% solar block); No shade but managed (NSD+WSP); cows were assessed at 1100 h and if mean respiration rate exceeded 80 breaths per minute the cows were walked 100 m to the dairy and sprinkled continuously for 45 min and then returned to their day treatment pen; Shade cloth (Rheem Australia Pty Ltd, 65% solar block) and a 2 km return walk to the milking shed between morning and afternoon milking (SCP+WLK). Within rows, means with common super-scripts do not differ (*P*>0.05).

Figure 1. Mean rectal temperature (ºC) for all of the experiment (light grey bars) and during the heat event (dark grey bars). The within treatment rectal temperatures during all of experiment and during the heat event differ (P<0.05) for all treatments except CID+SP.

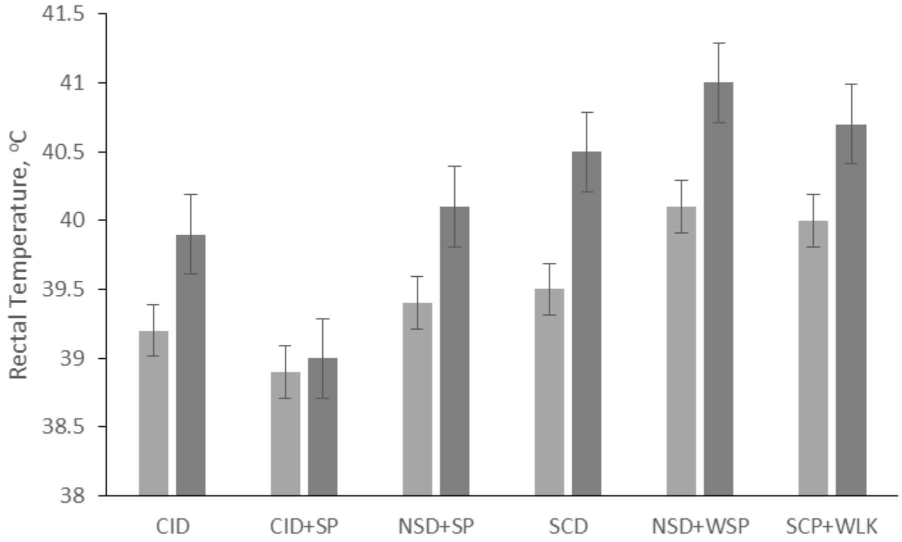

Figure 2. Mean respiration rates (breaths per minute: bpm) for all of the experiment (light grey bars) and during the heat event (dark grey bars). The within treatment respiration rates during all of experiment and during the heat event differ (P<0.05) for all treatments except CID+SP.